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THE NATURE OF THE ELECTRICAL PROPERTIES AND MAGNETIC SUSCEPTIBILITY OF THE INTERMETALLIC COMPOUND Mg_2Sn

[An unedited draft of this report follows.]

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THE NATURE OF SOME ELECTRICAL PROPERTIES AND MAGNETIC SUSCEPTIBILITY OF THE INTERMETALLIC COMPOUND Mg_2Sn

B. I. Boltaks,

Leningrad Phy-Tech Inst

Acad Sci USSR

Submitted 21 Jul 49.

Note: A long abstract of the following article may be found in Chemical Abstracts, by N. Thon, Vol. 44, No. 18 (25 Sep 50), p. 8179. A mistake is made in Thon's abstract; namely, the formula given as $\mu = CT^{\frac{1}{2}}$ should be $\mu = CT^{-\frac{3}{2}}$.

Author's abstract: In this work the author investigates the temperature dependence of specific electrical conductivity, Hall's constant, thermo-emf and magnetic susceptibility of the intermetallic compound Mg_2Sn. On the basis of the study of electrical properties it is concluded that Mg_2Sn must belong to the class of admixture semiconductors. From the data on temperature behavior of magnetic susceptibility a conclusion is made concerning the composite heteropolar and metallic nature of the bond in this compound.

I. ELECTRICAL PROPERTIES OF Mg_2Sn

Introduction

Among the intermetallic compounds known at the present time and possessing normal valence, phases of the type Mg_2Sn have served as an object of many investigations. Interest in these compounds is due to that peculiar "border" position which these compounds assume among the ordinary alloys and chemical compounds (namely salts)(1). Such a "border" position causes these compounds to have properties that pass from purely heteropolar compounds to metals and alloys with metallic type of bond.

The phase diagram of the Mg-Sn system (Figure 1) was first investigated by Kurnakov and Stepanov (2). They found that when the ratio of components is 70.95% (weight) Sn and 29.05% (weight) Mg the diagram of state has a sharply expressed definite maximum. The compound Mg_2Sn corresponds to just this ratio. In the case of deviations from stoichiometry (physical chemical law of definite multiple proportions) Mg_2Sn forms a eutectic with its components. As yet the problem of possibly forming solid solutions of Mg_2Sn with Mg and Sn has not been solved.

X-ray analysis showed that the compound Mg_2Sn has a crystalline structure anti-isomorphic to the fluorspar structure with four molecules in an elementary cell and with a lattice constant equal to a = 6.765 Å (4).

Further investigations by Kurnakov and Stepanov and by Grube (8) and others showed that the electrical resistance of this compound is much higher than that of Mg-Sn alloys with the ratio of components different from stoichiometry (Figure 2).

Attempts also were made to measure the temperature behavior of resistance of Mg_2Sn. Therefore Grube and Vosskuler (5) investigating the thermal conductivity of the Mg-Sn system relative to the ratio of components noticed that in the vicinity of the composition corresponding to the compound Mg_2Sn the temperature coefficient of electrical conductivity, starting at a certain temperature, changes sign: from room temperature to 450°C the resistance of samples increases with temperature, but at 450°C the temperature coefficient drops abruptly and finally at 525°C becomes negative. Such an anomalous behavior of electrical conductivity at that time seemed inexplicable.

Mott and Jones (6) basing their computations on quantum mechanics showed the possibility of Brouillon zones in Mg_2Sn. They proved that a Brouillon zone exists for the Mg_2Sn structure with a capacity corresponding exactly to an electron concentration equal to 8/3 electrons per atom. This value of concentration coincides exactly with the valence number of electrons in

Mg_2Sn pertaining to an atom, and we are dealing with a zone fully completed. The next brouillon zone will be empty. In this respect Mott and Jones expressed the assumption that Mg_2Sn in the pure state should be an insulator.

A very interesting question is what type of bond is in this compound. Kurnakov and Zintl consider Mg_2Sn a usual heteropolar compound, assuming that the bond is a consequence of mutual Coulomb forces between the positive Mg ions and the negative Sn ions. On the contrary, Mott and Jones suggest that Mg_2Sn should be considered not as an ionic compound, but as an "electron" compound of the Hume-Rothery type. But this last suggestion contradicts experimental data by Hume-Rothery himself and Raynor. [9], who did not succeed in obtaining a triple alloy by partial substitution of Mg atoms in this compound by Al or In atoms without a change of electron concentration. Other writers (A. F. Ioffe [7], N. V. Ageyev [8], and Dehlinger [13]) think that compounds similar to Mg_2Sn have bonds of mixed type; that is, partially heteropolar and partially metallic.

The author of the following report undertook the present investigation in order to obtain a detailed study of the nature of the electric and magnetic properties of Mg_2Sn. It consists of two parts: 1) investigation of the temperature dependence of specific conductance, Hall's constant and thermo-emf of Mg_2Sn; and 2) investigation of the temperature dependence of magnetic susceptibility of Mg_2Sn.

The results mentioned have already been presented by the author in two previous reports [10, 11].

1. Procedure Followed in Preparation of the Samples

The basic components for preparation of Mg_2Sn used in these experiments were chemically-pure magnesium and tin. The content of impurities in magnesium did not exceed 0.01-0.02%; and in tin, 0.05%.

The alloys were prepared in a molybdenum furnace under a carnallite layer in a crucible made of very pure graphite.

For the preparation of these alloys the author followed the procedure described by Kurnakov and Stepanov [2] and by Grube [3, 5]. A graphite crucible is filled with a magnesium and tin batch, in such a way that magnesium is below and tin above. The crucible is filled with a thick layer of flux above the metals and introduced into the furnace. At 700°C when the whole mass has already become liquid it is mixed well with a graphite rod. During mixing the temperature of the melt is raised 100°C. Thereafter the melt is heated still further to 1000°C and thereupon slowly cooled. The whole melting process usually takes 2.5 to 3 hours. In this way rather homogeneous bluish ingots are obtained, and their composition does not differ much from the initial ones. When heated rapidly Mg_2Sn's reaction of formation is rather stormy, with eruptions of a part of the alloy.

Separate meltings were processed according to Kubashevskiy's method [14]. In this case the initial components Mg and Sn are pulverized into fine powder, from which round tablets are pressed. The crucible is heated preliminarily to 500-550°C; thereafter the tablets are placed into the crucible and the heating is continued for 15-20 minutes until 650°C. When the formation of Mg_2Sn begins to react the temperature of the melt is raised rapidly and with weak heating for 8-10 munutes reaches 1000°C. The melt is slowly cooled for 45-60 minutes as in the first case. The ingots obtained are used for the preparation of samples to be used in investigations of their electric and magnetic properties. These samples were preliminarily tempered in sealed ampoules of hard glass for 20-30 hours at a temperature of 400°C.

2. Dependence of Specific Conductivity Upon Temperature

The electrical conductivity of Mg_2Sn was measured over a wide temperature range from -170°C to +400°C with equipment and methods described previously for Mg_3Sb_2 [18]. In this case the dependence of electrical conductivity and temperature coefficient upon the amount of deviation of the sample's composition from stoichiometry was investigated.

Table 1 shows the specific electrical conductivity and chemical composition of some samples at 20°c.

As follows from this table, the more the sample deviates from stoichiometric composition, the higher is the sample's specific electrical conductivity. Samples most approaching the stoichiometric composition have the smallest specific electrical conductivity; that is, the highest specific resistivity. It should also be noted that specific electrical conductivity of pressed samples is always nearly a whole order of magnitude higher than that of samples cut out from ingots, which fact is probably due to transitional resistances between separate crystals.

The temperature dependence of specific electrical conductivity is represented in Figure 3 for some samples investigated. From these graphs it is also easy to derive the temperature coefficient of electrical conductivity ivity. Samples with a composition very different from Mg_2Sn possess a negative temperature coefficient of electrical conductivity, and their electrical conductivity approaches the metallic one. When the composition approaches stoichiometry, specific electrical conductivity decreases and the temperature coefficient changes sign.

Samples with stoichiometric composition and also samples with small deviations from stoichiometry possess at room temperature a specific electrical conductivity of the order 2 - 60/ohm·cm.

Some Mg_2Sn samples with excess metal of the order 2 - 3% show at low temperatures a negative temperature coefficient of electrical conductivity, but show a positive one starting around 300°C, exactly as it happened in tests by Grube and Vosskuler[5]. Such a temperature behavior of electrical conductivity is represented in Figure 3 (second curve from above).

A positive temperature coefficient of electrical conductivity with presence of electron conductance is, as is known, typical of semiconductors. Therefore it is natural to consider the author's experimental data on the temperature behavior of electrical conductivity of Mg_2Sn from just this point of view.

Figure 4 represents the logarithm of specific electrical conductivity versus 1/T for two stoichiometric Mg_2Sn samples. As is seen from the graph, the temperature coefficient of electrical conductivity has a negative sign and different values for low and high temperatures. At low temperatures the coefficient is much lower than at high temperatures. With sufficient approximation, the temperature dependence of specific electrical conductivity (sigma) may be expressed in this case by the following formula:

$$\sigma = A_1 e^{-\frac{\Delta E_1}{2kT}} + A_2 e^{-\frac{\Delta E_2}{2kT}} \qquad (1)$$

Here A_1 and A_2 are constants; ΔE_1 and ΔE_2 represent the activation energy of electrons at low and high temperatures respectively; T is the absolute temperature; k is Boltzmann's constant.

The activation energies ΔE_1 and ΔE_2 of electrons which we determine from the slope of the straight lines characterizing the ratio $\log \sigma$ and 1/T are equal respectively to 0.03 eV and 0.2 eV. Therefore the formula's first term, where ΔE_1 has a small value, is predominant at low temperatures, and the second term dominates at high temperatures.

As is known, the temperature dependence of electrical conductivity of type (1) above is typical for semiconducting alloys. Because it occurs with stoichiometric Mg_2Sn samples it may be suggested that in this case one is dealing with a semiconducting alloy. But in order to have a clear picture of the conductivity mechanism of Mg_2Sn and to be able to make the positive statement that a compound of this composition is really a semiconductor, the study of only the temperature behavior of its electrical conductivity is obviously not sufficient. First it is necessary to know how the concentration of charge carriers varies with temperature and with it their mobility. For this purpose one must measure the temperature behavior of Hall's constant for a number of samples.

3. Measurement of Hall's Effect. Concentration of Conducting Electrons and Their Mobility

Hall's effect was measured according to standard methods in a static magnetic field and with dc current. Readings were performed over the temperature range -170°C to +400°C at H = 10,000 to 12,000 oersted.

Hall's constant varied in samples of composition approaching Mg_2Sn depending on temperature from 23 cm^3/abs-amp.sec at high temperatures to 6 cm^3/abs-amp.sec at low temperatures.

In samples with great excess of one of the components Hall's constant was of the order of 0.1 to 1.0 cm^3/abs-amp.sec.

Figure 5 represents graphs of Hall's constant versus temperature in two extreme cases; namely, a sample of stoichiometric composition and a sample with great excess of tin. The ordinate axis shows values of log R, and the abcissa is 1/T.

As is seen from these graphs (particularly from the stoichiometric one), the curve describing the ratio of the logarithm of Hall's constant (R) to 1/T, like the curve in Figure 4, contains two rectilinear parts with different slopes relative to the abcissa; namely, a small slope at low temperatures and a large one at high temperatures. The values of ΔE_1 and ΔE_2 determined from the slopes of the rectilinear portions possess the same numerical values, as computed from the temperature dependence of specific electrical conductivity. As for the sign of Hall's constant, it was always negative for all samples investigated by the author; that is, it corresponds to electron conductance.

From data on Hall's effect the author also computed the concentration of electron conductance in the samples investigated. The temperature variation of concentration may be followed in Figure 5, where the values n besides R are also marked on the ordinate.

As is seen from this figure, in a sample of stoichiometric composition the electron concentration rises with temperature from around 3.10^{18} at 100°K to about 3.10^{19} at 700°K. In samples of non-stoichiometric composition the concentration nearly does not vary with temperature and has a value of the order of 10^{21} cm^{-3}.

In order to explain the mechanism of conductance, the question of electron mobility within this compound is of great interest.

In samples that deviate from stoichiometry, the mobility of electrons decreases with temperature rise according to the law $u = CT^{-\frac{3}{2}}$, varying from 50 - 60 cm^2/volt.sec at 100°K to 5 - 7 cm^2/volt.sec at 700°K (Figure 6, curve b). In samples of stoichiometric composition the dependence of electron mobility upon temperature has a more complicated character. At low temperatures down to about 400°K the mobility rises with rising temperature and starting at 400°K the mobility decreases (Figure 6, curve a). The reasons for this occurrence are not yet clear, but one may assume that two competing mechanisms of electron scattering occur creating the strange temperature dependence of mobility.

As was theoretically shown not long ago by Weisskopf (15), and experimentally confirmed by a number of investigators in studies of silicon's electrical properties (18), the mobility varies with temperature according to the following law when small amounts of impurities, or admixtures, are present in the lattice:

$$u = aT^{3/2} + bT^{-3/2} \qquad (2)$$

where a and b are constants.

The first term of this formula is due to the scattering of electrons by impurities and is predominant at low temperatures [sic] when the thermal oscillations of the lattice do not have an essential role; the second term is due to electron scattering by the thermal oscillations of the lattice and predominates at higher temperatures [Note: These statements will hold only if the so-called first term is taken to be $bT^{-3/2}$ and the second term as a $aT^{3/2}$; that is, in contrast to usual convention of first and second]. In the case of stoichiometric samples of Mg_2Sn, as should be expected from curves a in Figure 6, the mobility varies with temperature according to a similar law

$$u = a_1T^{n_1} + b_1T^{n_2} \qquad (2')$$

here n_1 and n_2 are of the order of 2.5.

It is possible that also in this case, when the amount of impurities is negligible, a similar mechanism of electron scattering occurs: namely, by impurities for low temperatures and by thermal oscillations of the lattice for higher temperatures. However, this question requires further investigations.

4. Thermo-electromotive Force

The author made thermo-emf recordings relative to copper electrodes within a temperature range from -170°C to +400°C. The temperature differences at the ends of the sample were determined by a differential thermocouple and lay in the range 10 to 15°C. The thermo-emf and temperature of the sample were measured by Feissner's compensator. The sign of the thermo-emf was determined by comparison with the thermo-emf of cuprous oxide. All samples of Mg_2Sn investigated showed an electron sign of thermo-emf, which fact coincides completely with data on the sign of charge carriers obtained in investigators of the Hall effect. Table 2 represents the thermo-emf of some Mg_2Sn samples at 20°C.

As seen from this table, the thermo-emf rises as the composition approaches stoichiometry. Samples that diverge consistently in composition from Mg_2Sn have thermo-emf values that are typical for metals. Some divergence in thermo-emf for samples of nearly identical composition are due to the fact that the data of chemical analysis pertain to the ingots, and not to the sample investigated. The ratio of thermo-emf to temperature for various Mg_2Sn samples is represented graphically in Figures 7 and 8.

As these figures show, thermo-emf drops with increasing temperatures, and drops faster for higher temperatures than for lower ones.

The data presented here on the value and temperature behavior of the thermo-emf of Mg_2Sn seem to confirm the semiconductive nature of the electric properties of this compound.

5. Brief Conclusions Concerning the Nature of the Electrical Properties of Mg_2Sn

The data obtained by the author on the temperature dependence of electrical conductivity, Hall's constant and thermo-emf allows one as it seems to him, to draw some conclusions as to the nature of the electrical properties of Mg_2Sn.

The type of temperature dependence of electrical conductivity, Hall's constant and the thermo-emf of Mg_2Sn and also the numerical values of electron concentration and their mobility and the temperature dependence of concentration and mobility are similar to those of mized semiconductors. The meaning of the activation energy $\Delta E_2 \cong 0.2$ eV which was determined previously by experimental curves can probably be considered as the width of the energy gap filled by Brouillon's zone in Mg_2Sn and the zone of conductance thereafter following; and ΔE_1 can be considered as the distance from the admixture level to the conductive zone.

At low temperatures, the electrical conductivity, Hall's constant and thermo-emf are determined by the electrons passed to the conductive level from the admixture levels that lie at a distance of the order of kT at room temperature from the bottom of the conductive level. At high temperatures, the natural, or proper, electrical conductivity probably plays the main role. This may explain the presence of two regions on the curves of electrical conductivity, Hall's effect and thermo-emf versus temperature.

For considerable deviations from stoichiometry the semiconductive behavior of the electrical properties of Mg_2Sn is due to metallic impurities, or admixtures.

II. MAGNETIC SUSCEPTIBILITY AND BOND TYPE OF Mg_2Sn

1. Application of Magnetic Analysis Methods for the Determination of the Bond Type

As mentioned above, until recently the problem of the bond type of the intermetallic compound Mg_2Sn had still been under discussion. Hence we considered it useful to complete the available experimental data on this matter, by investigating this compound's type, value and temperature dependence of magnetic susceptibility.

As is known, the magnetic properties of a solid depend essentially on the bond type possessed by the particles making up its structure (atoms, ions and molecules)(19). As a rule chemical compounds tend to form complete electron shells; that is, tend to acquire the atomic structure of inert gases. It means, from the point of view of the magnetic properties of substances, that the formation of a chemical compound is followed by a mutual compensation (or at least a decrease) of the magnetic moments of atoms.

In the simplest heteropolar compounds (that is, compounds in which the elements forming them have completed their inner electron shells) theeformation of heteropolar bond is always followed by the appearance of diamagnetic susceptibility independent of temperature. The formation of a chemical bond in other heteropolar compounds may be judged by the presence of a change in effective magnetic moment, which may be computed from the temperature behavior of magnetic susceptibility mu:

$$\mu_{eff} = 2.84\sqrt{\chi_{mol}\cdot(T-\theta)}\cdot\mu_0 \qquad (3)$$

where chi χ_{mol} is the molar susceptibility of the substance; T is the absolute temperature; theta θ is the temperature correction defining the discrepancy from Curie's law, and μ_0 is Bohr's magneton. Here the value of the effective magnetic moment not only indicates the bond type, but often also determines the valence of ions.

A characteristic property of metallic bonds (except of ferromagnetic metals) is that the diamagnetic and paramagnetic susceptibilities are independent of temperature.

The author shall try here to analyse the question of what is the possible bond type in the Mg_2Sn investigated.

In as much as both metals Mg and Sn of Mg_2Sn compound are paramagnetic, one may assume a priori that the value and sign of the magnetic susceptibility of Mg_2Sn is defined by the state of the atoms in the lattice and by the degree of their ionization. If Mg_2Sn were merely a simple mixture of two metals — in other words, if the bond of this compound were of a purely metallic type — its magnetic susceptibility would be paramagnetic and independent of temperature. (Figure 9a).

On the contrary, if Mg_2Sn were a purely heteropolar compound, it should have diamagnetic susceptibility independent of temperature (Figure 9b). As will be shown below, experimental data does not agree with any of these models, which fact probably proves that this compound possesses a more complicated type of chemical bond.

2. Procedure to Determine Magnetic Susceptibility, and Experimental Data

The author chose the method by Gui [sic; Hooey, etc?] for measuring the magnetic susceptibility of Mg_2Sn. The whole equipment, scale, suspended sample and compensation apparatus were placed under an evacuated bell jar, which eliminated the air turbulence produced by the heating of the pipe with the suspended sample. The optic system attached to the scale allowed a reading accuracy three times higher. The electromagnet used enabled one to obtain a field strength as high as 12,000 oersted for a 30-mm gap and same diameter of the pole shoes.

The magnetic susceptibility was measured within the temperature range from -170°C to +400°C.

In order to eliminate the disturbing effect of possible ferromagnetic impurities, the measurements were performed at every temperature over a wide range of magnetic field strengths, and the values obtained for susceptibility were extrapolated to H = ∞ . It is natural that this method would introduce some errors, thus making the accuracy of determination of the magnetic susceptibility quite small. The error was of the order of 8 - 12%, and in some cases it was 15 - 20%. Therefore the author considers the results of his investigation of magnetic susceptibility rather qualitative.

Table 3 represents data on magnetic susceptibility of some Mg_2Sn samples at 20°C depending on the degree of deviation of their composition from stoichiometry. For comparison values of chi χ for pure Mg and Sn are given. As is seen from this table, when the composition of the samples approaches stoichiometry paramagnetic susceptibility decreases. Stoichiometric samples are diamagnetic.

The ratio of magnetic susceptibility and temperature of some Mg_2Sn samples investigated by the author is graphically represented in Figures 10 and 11.

These graphs show that samples in which the ratio of components differs considerably from stoichiometry have a paramagnetic susceptibility that slowly drops with temperature within the whole temperature range (Figure 10, two upper curves). Samples with a composition sufficiently near to Mg_2Sn have also a paramagnetic susceptibility that drops at ordinary temperatures, but changes to a diamagnetic susceptibility that rises with temperature even at 150 - 200°C (Figure 11).

Samples that possess stoichiometric composition are characterized by diamagnetic susceptibility that always rises with temperature, from room temperatures on (Figure 10, lower curve). For lower temperatures these samples are either non-magnetic, or weakly paramagnetic.

3. Discussion of Data on Magnetic Susceptibility

The experimental data available show that pure Mg_2Sn samples are probably really diamagnetic, but their susceptibility rises with temperature. As previously mentioned, this data does not agree with any of the models suggested (metallic or heteropolar bond) and proves that a compound of this composition has a more complex type of bond.

One could assume that the temperature behavior of susceptibility obtained experimentally is a consequence of superposition of some "foreign" paramagnetic susceptibility, decreasing with temperature according to the Curie-Weiss law on the diamagnetic susceptibility of the Mg_2Sn compound. But such "foreign" paramagnetic susceptibility cannot be the consequence of the presence of ferromagnetic impurities, since these were taken into account in the procedure followed for determining chi χ. An admixture of rare earth elements, which could effect a similar temperature behavior of chi χ, is not present, as was proved by chemical analysis. Therefore it remains to assume that the observed temperature behavior of chi χ is effected by the phenomenon of superposition, on the diamagnetic susceptibility of the Mg_2Sn compound, of a paramagnetic susceptibility of some ions with constant magnetic moments composing part of the given compound. Such ions may be, for example, Sn^{+}, Sn^{2+}, Sn^{+2} and others.

It is also possible that the observed temperature behavior of magnetic susceptibility is effected by quite other causes. Therefore, for example, the rise of diamagnetic susceptibility with temperature may be produced by the displacement of the density of the atom's (or ion's) electron cloud with temperature.

Let us try now to draw some conclusions on the bond type of Mg_2Sn.

Previously mentioned is data on the concentration of conducting electrons in the Mg_2Sn compound, as determined by data on the Hall effect (about 5.10^{18} at 300°K). Such a small concentration is obviously insufficient to produce

a metallic bond. On the other hand data on magnetic susceptibility, "non-metallic" structure, high fusing point, and great heat of formation of this compound confirm the conclusion that a purely metallic type of bond in this compound is entirely out of question.

On the other hand, the author's investigations of the temperature behavior of magnetic susceptibility deny the possibility of a purely heteropolar bond. Therefore one should assume that the bond type of Mg_2Sn is of a kind both like that of the ions Mg^{2+} and Sn^{4-} possessing standard valence bonds and forming a basic lattice skeleton, and also like ions with constant magnetic moments (of the type Sn^{+}, Sn^{2+}, Sn^{-}, Sn^{2-} and others).

It is natural that mutual Coulomb forces among such incompletely ionized atoms will be much weaker than among normal ions. This phenomenon in its turn causes a certain "weakening" of the bonds in the lattice itself, which probably explains why intermetallic compounds similar to Mg_2Sn posses a wide region of homogeneneity.

Conclusion

The study of the electric properties of the intermetallic compound Mg_2Sn enables one to conclude that this compound may be considered as belonging to the class of semiconducting alloys with a width of forbidden zone equal to about 0.2 eV.

The investigation of the magnetic properties confirms assumptions, previously expressed by a number of writers, concerning the mixed heteropolar and metallic type of bond in this compound.

Finally the author expresses his gratitude to V. P. Zhuze for his general direction of the work and to the Academician A. F. Ioffe for his valuable advice and discussion of results.

REMARK. After having already delivered this article to print, the author was informed about the work by Robertson and Uhlig [20] on the electric properties of the intermetallic compounds Mg_2Sn and Mg_2Pb. Robertson and Uhlig were led to the same conclusions as derived by the present author.

It is necessary to remark that the basic experimental data was obtained by the author in 1946-1947 and was partially published in Academician A. F. Ioffe's article entitled "Semiconductors and Alloys", issued in the collection "General Meeting of the Academy of Sciences USSR" 10-13 June 1947, but the American writers do not refer to this article.

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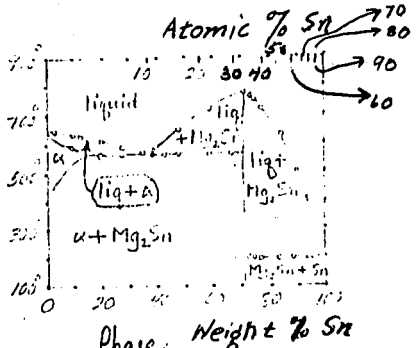

Figure 1. Diagram of State of the Magnesium-Tin System.

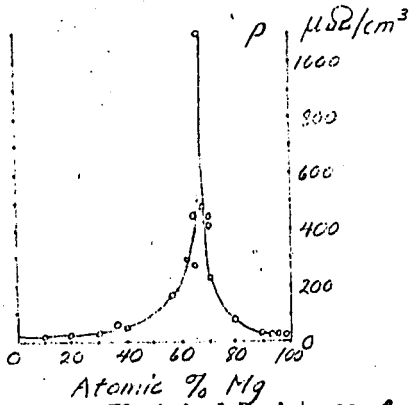

Figure 2. Electrical Resistance of Alloys of Magnesium with Tin.

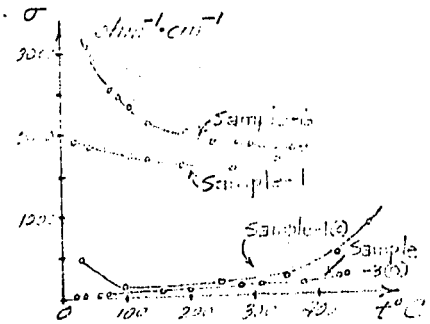

Figure 3. Temperature Dependence of the Specific Electrical Conductivity of Magnesium-Tin Alloys.

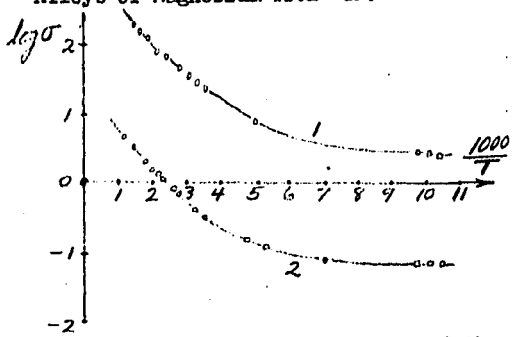

Figure 4. Temperature Dependence of the Electrical Conductivity of the Compound Mg_2Sn . U = 0.2 ev . 1- crystallic sample; 2- compressed sample.

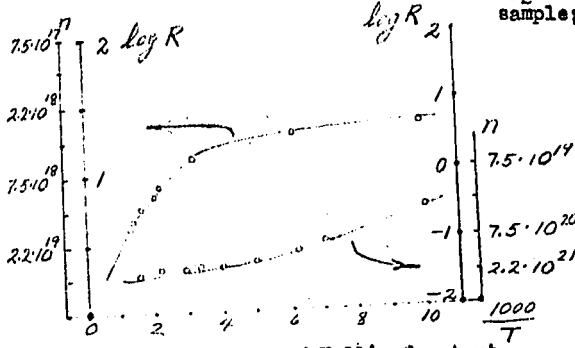

Figure 5. Dependence of Hall's Constant upon Temperature. The values of log R and n for the lower curve are read off the right ordinate axes, as indicated.

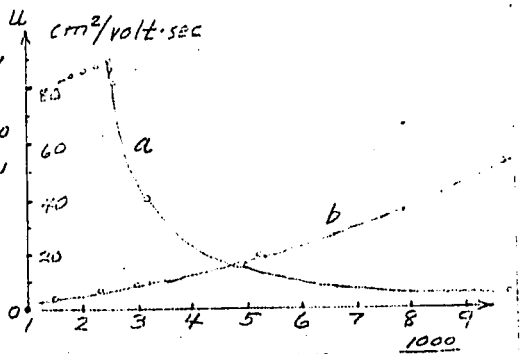

Figure 6. Dependence of the Mobility of Electrons upon Temperature.

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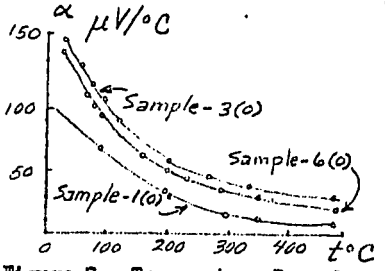

Figure 7. Temperature Dependence of Thermo-emf for Various Samples.

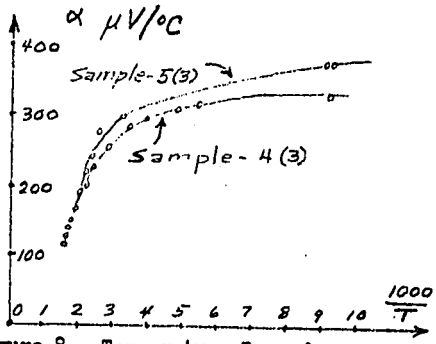

Figure 8. Temperature Dependence of Mg_2Sn Samples Possessing Stoichiometric Composition.

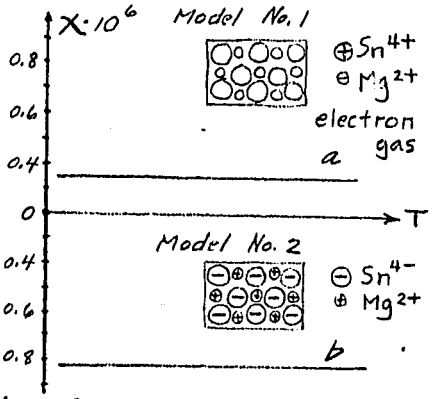

Figure 9. Possible "Models" of Mg_2Sn and Their Susceptibility.

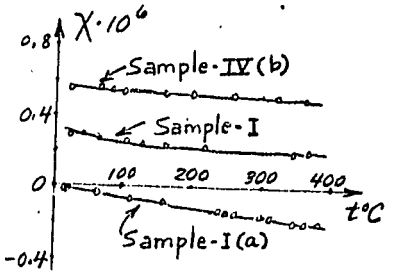

Figure 10. Temperature Dependence of the Magnetic Susceptibility of Various Mg_2Sn Samples.

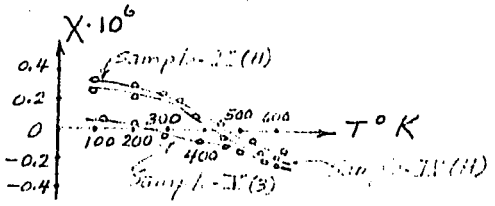

Figure 11. Temperature Dependence of the Magnetic Susceptibility of Various Mg_2Sn Samples.

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Table I. Specific Electrical Conductivity of Certain Mg_2Sn Samples at 20°C

Sample Number	Composition % Weight Sn	Mg	Excess of One of the Components	Sigma (Specific Electrical Conductivity) ohm·cm	Preliminary Treatment of the Samples
2	73.1	26.9	7.6 Sn(%)	2130	pressed, heated
1(0)	68.0	32.0	4.0 Mg	486	pressed, not heated
1	68.5	31.5	3.4 Mg	1860	pressed, heated
2(0)	72.0	28.0	3.0 Sn	223	pressed, not heated
3(0)	71.1	28.9	0.7 Sn	31.6	pressed, not heated
3	71.1	28.9	0.7 Sn	61.2	pressed, heated
5(3)	70.95	29.05	0.0	2.0	pressed, heated
4(3)	70.95	29.05	0.0	39.8	crystal, heated

Table 2. Thermo-emf of Various Mg_2Sn Samples at 20°C

Sample Number	Composition, % Weight Mg	Sn	Deviation (%) from Stoichiometry	Alpha Thermo-emf $\mu V/°C$
2	26.9	73.1	7.6 Sn	1 - 2
6(0)	27.0	73.0	5.5 Sn	26.9
1	32.0	68.0	4.0 Mg	94
1(0)	31.5	68.5	3.4 Mg	37.5
3(0)	28.9	71.1	0.7 Sn	154
3	28.9	71.1	0.7 Sn	146
5(3)	29.05	70.95	0.0 -	305

Table 3. Magnetic Susceptibility of Certain Mg_2Sn Samples at 20°C

Sample Number	Composition, % Weight Mg	Sn	Deviation (%) from Stoichiometry	Magnetic Susceptibility $\chi \cdot 10^6$	Character of Magnetic Susceptibility
IV(B)	15.1	84.9	30 Sn	0.550	Paramagnetic
I	31.6	68.4	3.6 Mg	0.270	Paramagnetic
II	27.9	72.1	3.4 Mg	0.250	Paramagnetic
IV(H)	28.15	71.85	2.9 Mg	0.220	Paramagnetic
V	29.0	71.0	0.1 Mg	0.022	Diamagnetic
I(a)	29.05	70.95	-	0.025	Diamagnetic
-	100	-	-	0.94 [illegible]	Paramagnetic
-	-	100	-	0.026 [illegible]	Paramagnetic

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